9 Anticosti Island: Geomorphological Context of a Unique Karst Area

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Abstract

The Gulf of St. Lawrence Lowlands geomorphological landscape region includes Anticosti Island, the Mingan Islands and several small areas bordering the Gulf of St. Lawrence, the Strait of Belle Isle and the Newfoundland Coastal Lowland. The region is underlain by the St. Lawrence Platform geological province whose formations are made up of different types and proportions of Paleozoic limestones and detrital rocks. Anticosti Island itself covers an area of 7,943 km^2 and is located between the Jacques-Cartier and Honguedo straits. The island is a monoclinal SSW dipping cuesta structure of carbonate strata with wave-cut terraces up to c.120 m asl. Two cuesta fronts and canyons are distinctive features of the island. The island was glaciated during MIS 2 and MIS 4. The central plateau and interfluves above 76 m are covered with thin discontinuous till (ground moraine) or thin (≤ 1 m) organic deposits. Outcrops of preglacial weathered bedrock remain. Karst features are found everywhere on the island. In most areas, karst is of recent Holocene age with shallow underground flows. The Upper Salmon River karst is the most developed and seems somewhat older and is partly inherited from an earlier period of karst development. Newly discovered springs and their associated dry valleys appear definitively older. The holokarst covers an area of ±23.7 km^2 and is fringed to the west and south by fluvikarst areas with surface and underground flows.

Keywords

Anticosti Island • Gulf of St. Lawrence Lowlands • Karst • Cuesta • Canyon • Salmon River

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9.1 Introduction

9.1.1 Historical Sketch

Anticosti Island is 222 km in maximum length, 55 km in maximum width and covers an area of ±7,943 km^2. It is located in the Gulf of St. Lawrence, between the Jacques-Cartier and Honguedo straits. It extends between latitudes 49°03′ N and 49°57′ N and longitudes 61°40′ W and 64°32′ W, between the Québec North Coast and Gaspé Peninsula (Fig. 9.1).

Anticosti Island, visited by people for 3500 years, was named *Notisquan* (where we hunt bears) by Innu (Montagnais) and *Natisgosteg* (foreland) by Mi'kmaq people. It was named *Isle d'Assumption* by Jacques Cartier in 1534, then *Île d'Enticosty* by Samuel de Champlain in 1625. The island was given to Louis Jolliet by Louis XIV in 1680. The famous French chocolatier Menier bought the island in 1895, built various infrastructures and in 1897 imported 220 deer. The deer population has now reached some 150,000. The island was bought by the Wayagamach Company, to become Consolidated Bathurst, in 1926. Finally, the Government of Québec bought the island in 1974, opening the door to cave and karst studies, among others. The 1974 caving report (Beaupré et al. 1974) suggested the creation of a thematic park for the Upper Salmon River karst.

Port-Menier, the only village of the island with its 240 residents, is in the western part of the island. It is equipped with an airport and a dock. Anticosti Island is a well-known fishing and hunting place as well as a recreational site, managed by the provincial parks department since 1980 which operates camps, lodges, pavilions and campgrounds. All are accessed using gravel roads. The Trans-Anticosti road, some 266 km long, runs from west to east on the northern side of the island. The Anticosti Parc national (572 km^2) has been operating since 2001 in the central part of the island. There are two ecological reserves: the eastern Heath Point and the southern Grand-lac-Salé. There are also

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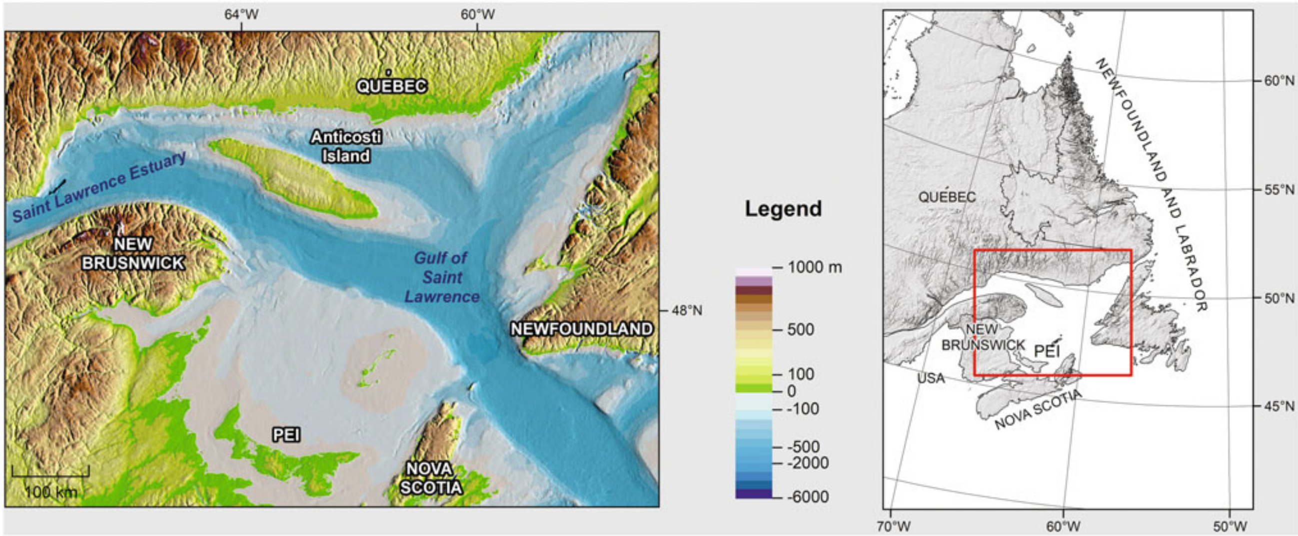

Fig. 9.1 Location of Anticosti Island. Background image adapted from Shaw and Courtney (2002). *Cartography* D. Kovanen

two outfitters, in the west and in the east, the rest of the territory being divided into numerous hunting sectors.

9.1.2 The Gulf of St. Lawrence Lowlands

The Gulf of St. Lawrence Lowlands are a part of the St. Lawrence Platform geological province that borders the Canadian Shield. It is a narrow, northeast extension of the stable interior of North America. The platform is underlain by relatively thin beds of, nearly flat-lying Cambrian to Lower Devonian orthoquartzites, carbonates and shales totaling 3500 m in thickness, that lie unconformably on the crystalline rocks of the Canadian Shield. The rocks of the Anticosti Basin consist of seven distinct formations, ranging from Upper Ordovician to Lower Silurian. These rocks are exposed on Anticosti Island, the Mingan Islands and several small areas bordering the Gulf of St. Lawrence, the Strait of Belle Isle and the Newfoundland Coastal Lowland (Fig. 9.2; see Chap. 7). Anticosti Island is a south dipping cuesta of carbonate strata. Wave-cut terraces to 120 m asl occur on both north and south sides, being generally lower on the south side. Most of the belt is less than 120 m asl, although the summit on Port au Port Peninsula, Newfoundland is at 360 m asl.

9.2 Climate, Hydrography and Vegetation of Anticosti Island

9.2.1 Climate

The island climate is temperate, with winter minimums higher than on the continent and cooler shorter summers, with frequent fogs. Climatic type is sub-polar, sub-humid (Köppen-Geiger Dfb) with an average growth season of ±171 days. Mean annual precipitation in Port-Menier is 1,005 mm, with 40% as snow. Mean annual temperature is 1.9 °C. July is the warmest month with a mean temperature of 14.8 °C, and February is the coldest one with an average temperature of −11.2 °C. Prevailing winds are from north-west and southwest (42% of the time) and from the northeast and southeast (33% of the time) (Boisclair 2004).

9.2.2 Hydrography

More than 10,000 km of water courses have been mapped on this island, 40% classified as intermittent. Rivers, lakes and ponds cover 214 km^2, 2.7% of the island area. There are 49 primary drainage basins covering an area of 5,800 km^2 (73% of the island), the remaining part being composed of residual basins (Fig. 9.3). Of the total number of water courses, 51 flow to the north and 52 to the south. Northern drainage basins are usually smaller and cover only one-third of the island. Basin areas range from 12 to 956 km^2, 24 being larger than 100 km^2. The most important ones are those of the Jupiter (956 km^2), Salmon (358 km^2), Chaloupe (209 km^2), Gallote (206 km^2), Otter (196 km^2), Vauréal (194 km^2), Oil (183 km^2) and Patate rivers (160 km^2) (Bazoge 2015). In the eastern and western lowlands rivers trend NNE–SSW and flow south or north, along or against the southern dip of the limestone strata. The dividing line between the northern and southern drainage basins follows the island center in the eastern part and passes more to the north on the western side. In the central plateau, rivers trend NNE–SSW and flow south or north, along or against the

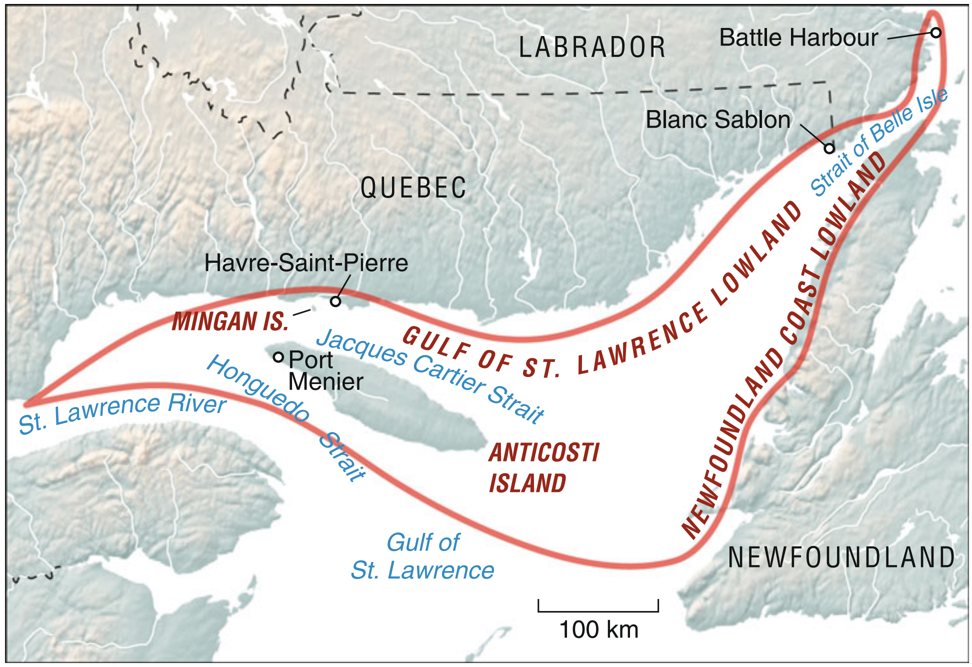

Fig. 9.2 **Outer limits of the** Gulf of St. Lawrence Lowland geomorphological landscape region. The Newfoundland Coast Lowland is one part of the Gulf of St. Lawrence Lowland. *Cartography* E. Leinberger

southern dip of the limestone strata. Salmon River and the upper part of the Jupiter River flow along the strike of strata (WNW–ESE).

Drainage networks are usually parallel on the southern side of the island, with rivers flowing along the natural slope. Networks are more rectangular on the northern side. Elsewhere networks are dendritic or rectangular with orientation mostly controlled by the main joint sets (NNE–SSW and ESE–WNW). Disordered networks prevail in the eastern part of the island and in its central part, at the head of Jupiter, Salmon and Vauréal rivers. Rivers are usually shallow with a flat rocky bed and crystalline waters. River entrenchment is small in the central plateau area and in the eastern lowlands. Entrenchment increases in the northern edge of the central plateau and on the dip side of the central cuesta, thus forming wide and deep canyons. On the northern side these canyons do not penetrate inland more than 10 km and rarely reach lands that are over 150 m (Fig. 9.4). On the dip side of the central cuesta they can reach 20 km in length, between the southern coast to the crest of the central cuesta. The change-over of non-entrenched rivers to canyons is usually associated with a rapid change in longitudinal slope.

9.2.3 Vegetation

The island is mainly covered with black spinet and balsam fir forests while the coastal area is mainly covered with white spinet and fir forests extending a few kilometers inland. Lumber activities have been going on for decades. Bogs and

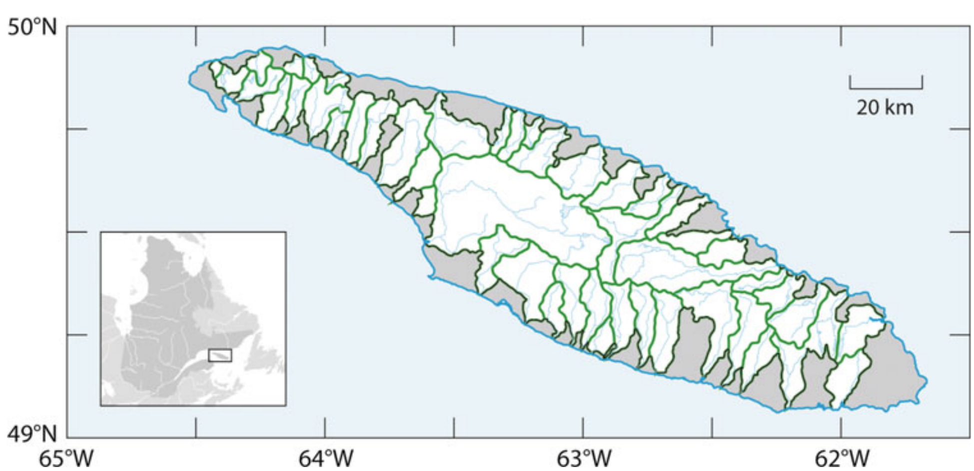

Fig. 9.3 Main drainage basins of Anticosti Island (after Bazoge 2015). *Cartography* E. Leinberger

Fig. 9.4 The upstream part of the Vauréal River canyon

fens cover some 25% of the island and are found mainly in the western and eastern lower regions and in the upstream part of Vauréal and Salmon rivers.

9.3 Physiography

The overall orientation of the island is WNW–ESE, somewhat parallel to the strike of limestone formations. Over 60% of this territory is below 120 m asl, while only 2.6% is over 240 m; maximum elevation reaches 313 m. The central plateau is edged by lowlands (≤ 150 m) developed on the eastern (east of Salmon and Dauphiné rivers) and western (west of Jupiter and Oil rivers) parts of the island. The central plateau is divided into the northern central plateau and the southern central plateau. The divide between these two parts runs at the foot of the central cuesta (Fig. 9.5).

The overall physiography of the island is highly influenced by the monoclinal structure of the sedimentary formations dipping slightly to the SSW (0.5–2.0°). Two cuesta fronts have been mapped: the northern one along the north coast with height reaching 100 m and the central one with heights less than 30 m. Both have developed during the Cenozoic era and were partially modified by glaciations during the Quaternary. Cuestas are poorly developed in the eastern lowlands. In the western lowlands they are small, numerous and cut by numerous valleys. Valleys are open or entrenched canyons. These canyons are one of the important and often spectacular features of Anticosti Island. Some, like the Jupiter River canyon, can reach depths of 100 m.

The central plateau shows few glacial erosion features and dendritic to disordered, possibly preglacial, drainage networks. Eastern and western lowlands show more significant glacial erosion features such as giant grooves and

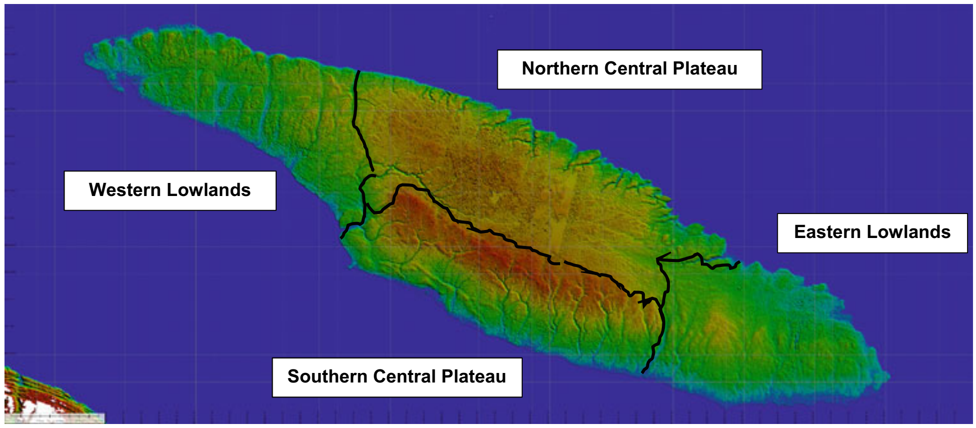

Fig. 9.5 Physiography and main divisions of Anticosti Island (SRTM)

"zig-zag" kilometric-shaped escarpments with funnel-shaped in-between valleys (Eyles and Putkinen 2014).

Many bedrock platforms, with width ranging from a few hundreds of meters to 2 km, can be seen along the island's 550 km coastline. They formed at different levels, most persistent ones having developed at 20.5 and 26 m levels. Some active cliffs can reach heights of 120 m in the middle-eastern part of the northern coast (Fig. 9.6). Fossil cliffs can locally reach more than 130 m in elevation in the northern coastal area. Active cliffs on the southern side of the island are usually lower (15–60 m) and less common.

9.4 Surface Materials

9.4.1 Studies

Surface materials on the island were mapped between 1980 and 1982 and a set of 1:50,000 maps has been published (Dubois et al. 1985). During this period numerous studies on glaciation/deglaciation of the island, marine invasion/regression, geomorphological and karst features and processes were completed. All these studies were completed by teachers and students at Sherbrooke University and a large set of related theses and papers was published.

9.4.2 Description

The island was glaciated during MIS 2 and MIS 4. Surface materials are usually scarce, especially in the central plateau and along interfluves above 76 m asl, 90% of the island area. These areas are covered with thin discontinuous till or thin (≤ 1 m) organic deposits. Four different till deposits have been mapped and are separated, in large valleys, by thick fluvial or marine sequences. Material from three of these tills was derived from the St. Lawrence North Shore, and the fourth one is related to a residual Anticosti cap. They are structureless, compact, homogeneous silty clayey sand with various amounts of cobbles and boulders. Most of the coarse fraction comes from the island, with only 4% from the North Shore. Thickness varies between 1 and 20 m. Glaciers, some 450–600 m thick, flowed southeast initially, then southwest. It seems that valleys did not influence glacier flow direction but served mostly as sediment traps. Some northern and southern fluviglacial deposits and frontal moraines were formed during the last central ice cap phase. Glaciers disappeared at ± 13 ka and marine regression started at ± 13.5 ka. Emergence rate of the island between 13 and 11 ka was around 2 m/100 years, but dropped to 0.25 m/100 years later ($11-6$ ka). Marine invasion reached a maximum at 80–85 m asl. Many terraces related to the marine regression have been mapped: at 70, 60, 40, 30, 25, 15 and 8–10 m asl. The largest accumulation of deposits is found along major rivers. Various types are present: glacial, fluviglacial, glacimarine, deltaic and alluvial. Frontal moraines have been mapped around the island, in its western half. Coastal deposits are frequent under 60 m asl in the eastern and western lowlands and on the island south side. They are also seen as terraces in the outlet area of northern rivers (Gratton et al. 1984; Painchaud et al. 1984; St-Pierre et al. 1987). Most karst features have developed in thin deposit areas.

Preglacial weathered bedrock does not appear to have been completely eroded away. Weathering debris up to 2.5 m thick is exposed in many areas and, in some places, regolith is covered by till. It seems that glacial erosion was not so intense in some parts of the island.

Fig. 9.6 Coastal active cliff in the Baie de la Tour

9.5 Geology of Anticosti

9.5.1 History of Studies

The Québec government bought Anticosti Island in 1974. Few geological studies were done before this event due to poor access. These studies mainly discussed lithological, paleontological and biostratigraphic aspects of this thick sedimentary sequence and, to a much lesser degree, geomorphological features and Quaternary deposits. The Québec government started a large geological mapping project at the end of the 1970s (Petryk 1981a, b, c). This new exploration phase coincided with the start of gas and petroleum exploration on the island. Since then, deep drilling and geophysical surveys have been done by the public and private entities. Many structural studies have been completed since to help understand the structural features and the tectonic framework of this island (Tanguay et al. 1986; Carboni 1988; Bordet 2007; Bordet et al. 2010; Brake and Pinet 2015; Pinet et al. 2015; SOQUIP 1985).

9.5.2 Limestone Sequence

Sedimentary rocks on the island range from Upper Ordovician to Lower Silurian and belong to the St. Lawrence Lowlands geological province and the Anticosti Platform of eastern Québec. They have been divided into seven formations (Vauréal, Ellis Bay, Becscie, Merrimack, Gun River, Jupiter, Chicotte, in decreasing age) based on their lithological characteristics (Desrochers and Gauthier 2009) (Fig. 9.7). Facies are more calcareous on the western side, with coarser clastic facies in the eastern part. These sediments were deposited in shallow marine environments. Thickness of formations ranges between 25 and 250+ m, and thickness of beds ranges between 5 and 20 cm. Most formations are made up of different lithological facies, ranging from coral reef rock, pure limestones of different grain sizes, and shaly, silty or sandy limestone interstratified with shale, siltstone or sandstone beds. The Merrimack formation (25 m) is made of very slightly soluble calcareous shales while the Chicotte formation (80 m) is composed of thick pervious limestone beds and coral reefs. The basal Vauréal and Ellis Bay formations tend to be more shaly, and are less prone to karst. Mapping of limits between each formation has been difficult because of gentle southern dips, the gradual facies changes, the lens-like nature of bedding, and difficult access. Primary permeability of these rocks is low, except in the Vauréal and Ellis Bay sandstones of the eastern part of the island.

The total thickness of this sedimentary sequence increases toward south and east, going from 915 m up north to more than 3,660 m in the south. Under this sequence are the black shales of the Macasty formation (gas schists), the sandstone and calcareous limestones of the Mingan formation, and the Romaine formation dolomites resting on the Precambrian rocks of the north coast. The last two formations outcrop in the Mingan Islands National Park.

Two vertical diabase dykes, 8 and 15 m thick, cut the Vauréal formation limestones in the central northern coast. They have been mapped along many kilometers and are related to the opening of the Atlantic during the Jurassic (Bedard 1992).

9.5.3 Structural Features

These limestone formations trend WNW–ESE, with gentle SSW dips. They are very slightly deformed by faults or folds. Four sets of vertical joints have been identified in the western part of the island (Bordet et al. 2010): a first orthogonal group with N–S and E–W joint sets and a second orthogonal one with ± NE–SW and NW–SE joint sets. A fifth irregular and random set has also been described. The first group is the most important one, and the second one has not been seen everywhere. Calcite fillings of joints are infrequent. The first joint set (N 082° − 110° E) is the most constant, with more regular and continuous joints. Strike of these joints tends to change from west (N 082° E) to east (N 110° E). The second set seems younger and shows two subsets (N 355° − 012° E and N 015° − 030° E). It is sometimes absent in the southern part of the island. These two sets are the most important ones and are usually found together. Karst features are mostly associated with these. The third and the fourth sets are minor and only seen locally.

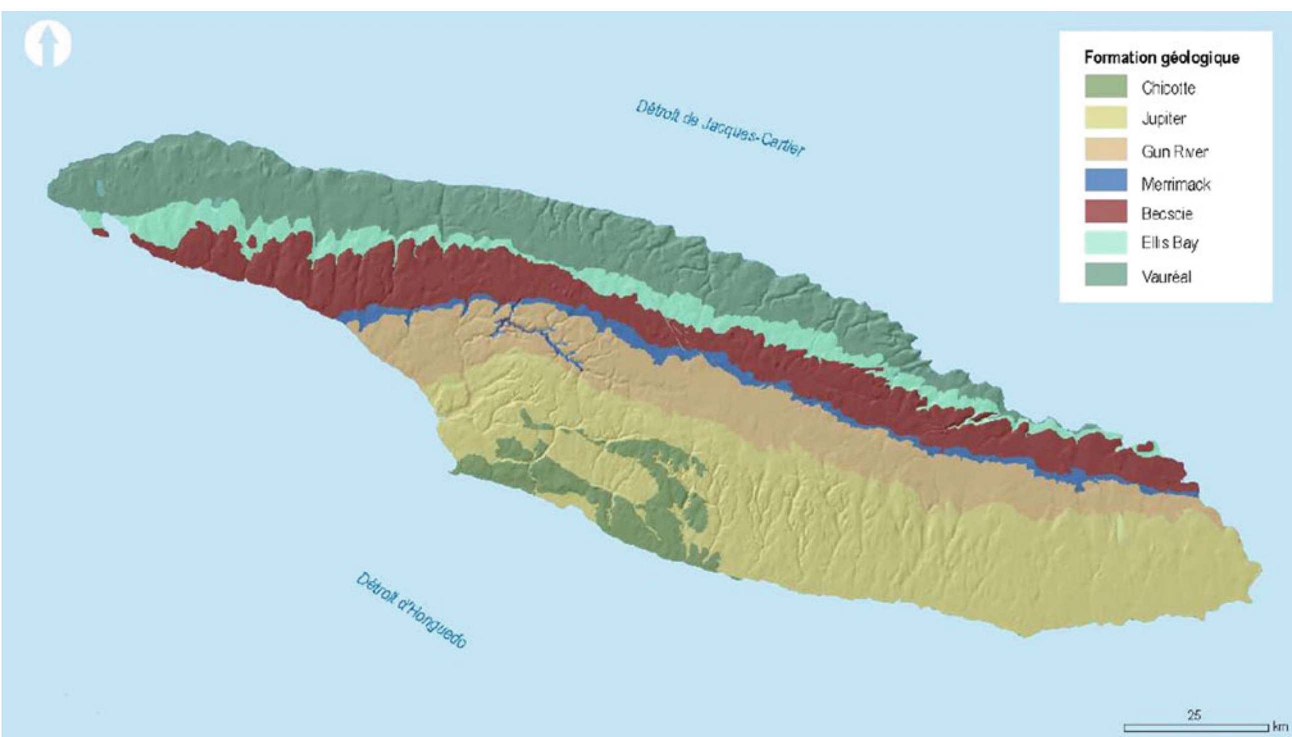

Fig. 9.7 Geological map of Anticosti Island (after Bazoge 2015; adapted from Desrochers and Gauthier 2009)

A few WSW–ENE trending open folds have been mapped in the southern Chicotte formation, elsewhere undulations being related mainly to sedimentary processes, not tectonic ones. Deep boreholes and seismic surveys have shown NW–SE trending gravity faults with 100–200 m drop of the southern block; some other gravity faults have been mapped with other trends. Faults are not easily seen on surface outcrops and displacements are small, between a few centimeters to a few meters (Bordet et al. 2010). Numerous sets of lineaments have been mapped on the island, some of them related to main joint sets or diabase dykes. Lengths range between 10 and 160 km (Brake and Pinet 2015; Pinet et al. 2015; SOQUIP 1985).

9.6 Karst

9.6.1 History of Studies

Karst studies began in 1974, following a first site visit to the island by members of the Société Québécoise de Spéléologie (Beaupré et al. 1974). The purpose of this reconnaissance was to evaluate and map as many features as possible based on local reporting. A second shorter visit was made in 1976 to acquire additional information on known features and explore new ones. Short caves and shallow pits were mapped. A study of the karst phenomena and drainage of the Upper Salmon River was completed during the 1976 summer and a thesis was published on this subject (Roberge 1979; Roberge and Ford 1983). A short caving trip was done in 1982 by members of the Société Québécoise de Spéléologie and a few known caves were mapped and dived.

Many surface karst features were mapped between 1980 and 1982 by Sherbrooke University personnel and students based on aerial photograph analysis and site visits. A synthetic map was published in 1990 (Dubois et al. 1990) showing the distribution of main karst features of the Anticosti karst.

During the same period, other studies concentrated on the geomorphological and hydrochemical processes associated with some karst lakes and drainage in the central plateau area (Cadieux 1983; Coté 1987; Coté et al. 2006; Lauriol et al. 1985). A few studies were done on specific caves, like the Grotte à la Patate (Roberge et al. 1985; Lauriol et al. 1987).

Clearing work was done, without results, during the 1992 and 1993 summers in the spectacular collapse sinkhole called *Abime du chevreuil*, in the downstream part of the Upper Salmon River karst. The 419 m long *Grotte des Trois-Plaines* in the western part of the island was mapped in 1996. The Québec Parks Department sponsored geomorphological and karst reconnaissances in 1996 and 2000 in the central and western parts of the island (Roberge 1996, 2000). A short visit was done in 2013 by the members of the Société Québécoise de Spéléologie to check changes in known karst features. A recent trip was done during the 2017 summer to revisit and reevaluate the main features of the Upper Salmon River karst (Beaupré et al. 2017).

Except for the significant work done by Roberge (Roberge 1979, 1996, 2000) and Sherbrooke University, most of the works completed on Anticosti karst features were quite specific (cave mapping and studies), usually reconnaissance or exploration work.

9.6.2 Karst Features

Even though karst studies have been fragmentary, incomplete and hindered by lack of good access, they suggest that karst features are found everywhere on the island, in all geological formations, in all areas and at all elevations (≤ 15 m − ≥ 220 m). The Upper Salmon River karst is, by far, the most developed karst, considering its area (38.5 km^2), its feeding drainage basin (143.6 km^2) and the length of some of its underground flows (≤ 14.1 km) (Roberge 1979). Elsewhere karst is in an embryonic stage with shallow underground flows (≤ 5 m) following surface drainage and fed by lakes, ponds, bogs or small brooks. The underground drainages are usually shorter than 1 km, always less than 2 km. Most of these phenomena seem to have developed recently, during the Holocene.

The mapping of surface karst features (Dubois et al. 1990) has shown that:

(a) East of Salmon River, sinkholes are few and concentrated in the Gun River formation and in the southern part of the Jupiter formation;
(b) West of the Jupiter River, sinkholes, karst areas and karst depressions have been mapped mainly in the Gun River and Becsie formations;
(c) In the central area between Jupiter and Salmon River, sinkholes, karst areas and karst depressions are concentrated in the central plateau area, along the Gun River formation, on the dip side of the central cuesta in the Jupiter formation and, to a lesser extent, in the Chicotte formation.

Some 79 karst zones have been identified in the island, with area ranging between 0.1 and 3 km^2. Karst features seen on the island were of the following types:

(a) Karren: millimetric, centimetric or metric-size surface features developed on rock outcrops or under very thin covers of surface materials or organic deposits;
(b) Open fractures: with widths ranging from a few centimeters to a few meters, lengths from a few meters to a few tens of meters and depths from a few meters

to ±18 m. This feature is the most frequent and well developed, mainly along E–W to ESE–WNW trending joints;

(c) Sinkholes: from a few meters to 1 km in diameter, with depths of a few meters to a few tens of meters, formed by solution, subsidence, collapse over large voids, or a combination of these processes;

(d) Sub-horizontal caves: active caves with lengths from a few meters to a few hundreds of meters, accessed from canyon sides, vertical shafts or springs. Only 8 are known, mainly along the Patate, Observation, Vauréal, Salmon rivers and the Malouin Lake, The longest one is Grotte à la Patate (625 m) (Fig. 9.8) followed by Grotte des Trois-Plaines (419 m) and Grotte de la Baie-de-la-Tour (264 m).

(e) Karst drainage: Many phenomena are related to underground flow: sinking streams in open fractures or sinkholes, surface or lake springs, blind valleys, dry valleys, karst windows, dry valleys and karst lakes. The longest underground flows are found in the Upper Salmon River karst (7–14 km). Elsewhere lengths range from a few hundred meters to less than 2 km. Of interest are those karst lakes found in the central plateau, inside a 60 km^2 area found west of Vauréal River (Fig. 9.9). The

Fig. 9.8 Entrance (spring) to *Grotte de la Patate*

hydrological behavior of these lakes is affected by open fractures, sinkholes and ponors. Lake-level variations depend mostly on the relation between local precipitation and karst seepage and can reach many meters. Levels gradually drop following snow melt and spring period, minimum observed levels being in winter. This progressive lowering of lake levels leads to a somewhat concentric zonation of littoral vegetation, intense ice dynamics and, in some cases, periglacial forms. The associated underground networks are small in extent, skin-deep and local. Most lakes are under 2 km^2 in area (Cadieux 1983; Lauriol et al. 1985; Coté et al. 2006).

(f) Residual hills: In the central plateau area, west of the Vauréal River, are hills with complex topography, usually less than 20 m in height but reaching locally 35 m, surrounded by flat surfaces. In some cases, they show rounded and profiled crests, in other bumpy or wrinkled veneers. They are densely punctuated with dry, often coalescing, depressions (Roberge 1996). These hills and depressions are highly variable in terms of dimensions, orientation, density, height, depth and area. In many cases they are located near embryonic karst or karst lakes and some seem derived from in situ bedrock. Surface is usually covered with cobbles and boulders, rarely by rock outcrops. Depressions show little relation with main joint sets and their form does not resemble glacial features. In some cases, these hills extend to rock surfaces with outcrops and karst pavements. Influence of structural features is clear north of Smith Lake where most depressions are trending N–S giving the impression of a labyrinth karst (Roberge 1996). Roberge (1996) suggests that they could be polygonal karst features partially eroded by glaciers while Cadieux (1983) sees them as regolith.

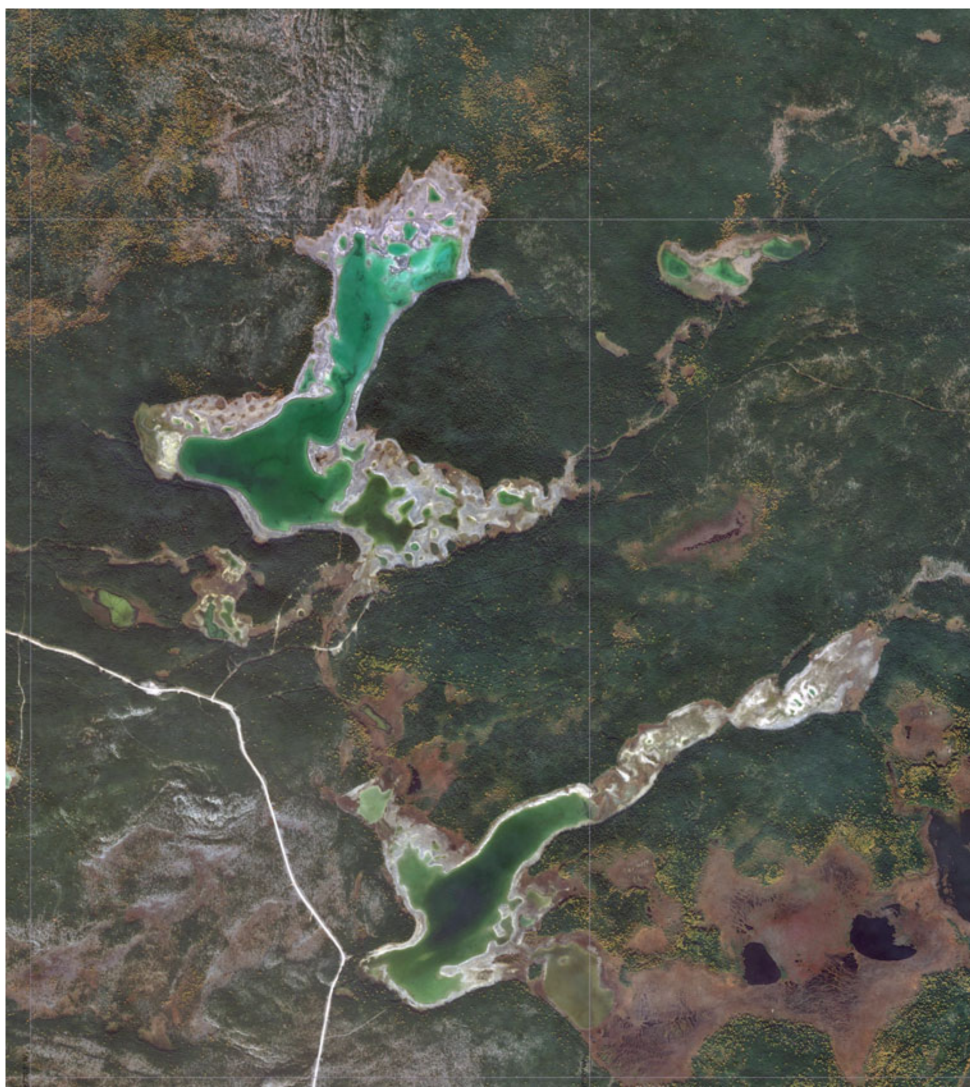

Fig. 9.9 Karst lakes in the Smith Lake area

9.6.3 Upper Salmon River Karst

This karst is, by far, the most important, developed and oldest one on the island. This is where surface karst features are spectacular. It has a WNW–ESE trend parallel to the strike of bedding and to the main joint set (N 110° E). Most features are found between elevations 170 and 190 m asl, with a main spring at 140 m asl. Maximum total drop is 60 m.

Karst features have developed mainly in the lower part of the Gun River formation and are limited to the north by the shale beds of the Merrimack formation and, to the south, by a more shaly section of the upper Gun River formation. Numerous peat bogs have formed south and west of the karst area and drainage network is disordered in those areas. Till thickness is usually less than 3 m.

The feeding basin (143.6 km^2) is divided into five non-karst sub-basins that are intercepted by open fractures or sinkholes when they enter the karst zone from the south (Fig. 9.10). Karst occupies some 27% of the basin and peat bogs 29% (Roberge 1979).

The holokarst, the area where there is no surface flow, covers an area of ±23.7 km^2 (2 × 12 km) and is fringed to the west and south by fluvikarst grounds with surface and underground flows.

The only known permanent spring is located at the eastern extremity of the karst, some 14.1 km from the Salmon River main sink (Fig. 9.11). Dye tracing tests have shown that it took less than 17 days ($\geq$ 0.85 km/day) for water to travel from sink to spring (Roberge 1979). Hydraulic gradients are small (0.2–1.0%) except near the main spring (6%). Karst seems to have developed from east to west.

Spring flow reacts more to heavy rainfall when the ground is soaked with water, that is when the spring outflow is large. Flood peaks were usually sharp and regular, with only one event per flood. Reaction time following a rainfall can be rapid, a few hours, suggesting pulse transfer in a saturated ground. Spring waters are under-saturated, suggesting rapid transit times and rapid flow. Chemical analysis of spring waters suggests water flow in a closed-circuit environment without access to CO_2 rich air.

Many karst features have been seen and mapped (Roberge 1979):

(a) Karst pavements where till is thin ($\leq$ 0.3 m) and forest is dry and open;
(b) Metric size open joints developed along the first and second joint sets where till is thicker (0.3–2.0 m);
(c) Infrequent subsidence sinkholes where till is thick ($\geq$ 2.0 m) (5–15 m wide, $\leq$ 4 m deep);
(d) Solution sinkholes developed along WNW–ESE joints and often associated with sinking streams. They are seen along water courses, dry beds or along peat bog edges. They can reach some 100 m in length and more than 10 m in depth. They can be active, intermittent or inactive, the last two types being often filled with till or alluvial material;
(e) Collapse sinkholes are the most spectacular ones. Five have been described by Roberge (1979), with volumes ranging from 300 m^3 to 6,000 m^3. Four are conical in shape while the last one, l'Abime du Chevreuil, is rectangular (44 × 4–7.5 × 18 m) (Fig. 9.12);

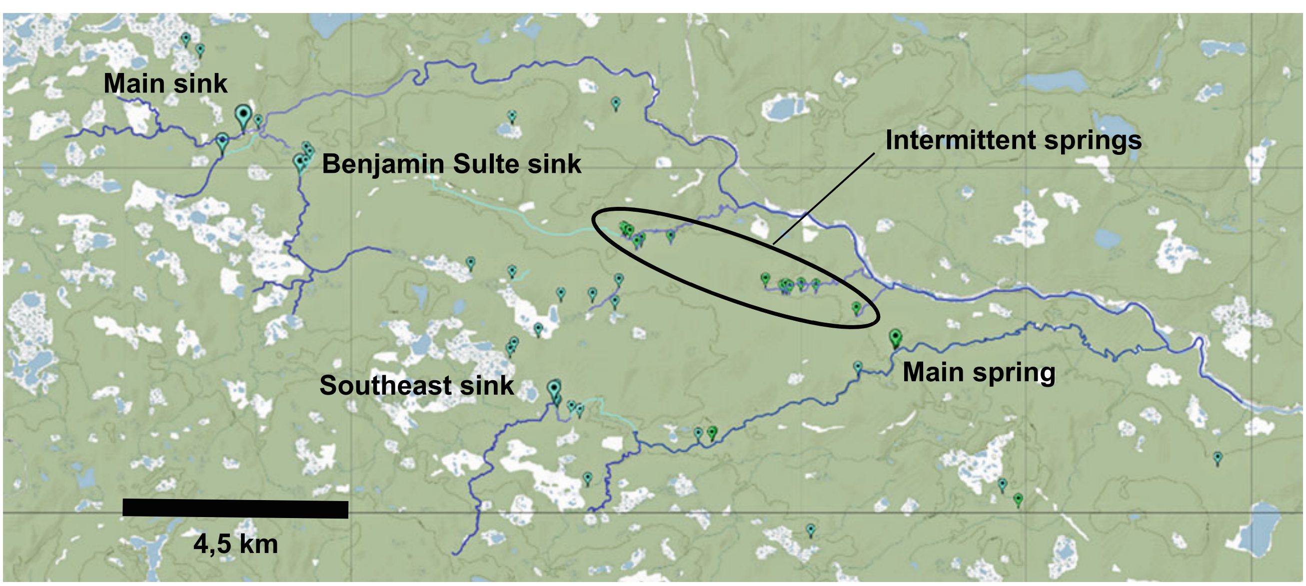

Fig. 9.10 The Upper Salmon River karst drainage (sinks in blue, spring in green)

Fig. 9.11 Main sink of Salmon River

(f) About ten deep sinkholes with steep sides (collapse, solution) are being used as creek sinks in the southern part of this karst;
(g) Some 20 km of dry, intermittent or permanent, stream beds have been mapped in this karst area. Many sinks filled with till, alluviums or organic debris are present (Fig. 9.13).

A recent visit to the Upper Salmon River karst has identified a series of intermittent springs on the north edge of the holokarst that seem to flow only in spring time or during large flood periods (Beaupré 2017; Fig. 9.14). They seem related to a westward old dry valley trending WNW–ESE, punctuated with large deep subsidence sinkholes. Head valleys associated with these springs are more developed and deeper than the main spring valley, suggesting that they are older.

Most karst features on the island are numerous, diversified and thought to be mainly Holocene in age. The Upper Salmon River karst with its large features and long drainage routes seems somewhat older and partly inherited from a previous karst development. The newly found springs and their associated dry valley appear definitively older.

9.7 Conclusion

This former huge private island seated in the Gulf of St. Lawrence has been, since its acquisition by the provincial government in 1974, the subject of many geological studies. Gas exploration, Quaternary studies to characterize glaciation and deglaciation history, and environmental studies to create a national park in a karst area, two ecological reserves and a set of more specific landmarks have been the subjects

Fig. 9.12 *L'Abime du Chevreuil*, a large collapse sinkhole

of these studies. Gas exploration has ceased and lumbering activity is on the decline. This island has become a salmon fishing and deer hunting paradise. Tourist activities are on the rise even though access by air or boat is not always easy and cheap, but those who visit the island are rewarded by something quite unique in the eastern part of Canada.

Karst studies have been somewhat slow moving since the 1970s, mainly because of the sheer size of the island, its remoteness, often difficult access to specific feature sites, and living conditions in the woods. Recently, the park service has been very helpful in facilitating access to remote and more interesting parts of the island, especially in the Upper Salmon River karst and in the southern parts of the national park. The size and variety of karst features and hydrogeological underground connections make this karst a quite unique feature in eastern Canada, more than worthy of future studies.

Fig. 9.13 The Benjamin Sulte River sink

Fig. 9.14 An intermittent spring on the northern edge of the holokarst

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